Mathematical Modeling for Removing Border Entry and Quarantine Requirements for COVID-19, Vanuatu

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The Pacific Island country of Vanuatu is considering strategies to remove border restrictions implemented during 2020 to prevent imported coronavirus disease. We performed mathematical modeling to estimate the number of infectious travelers who had different entry scenarios and testing strategies. Travel bubbles and testing on entry have the greatest importation risk reduction.

Many Pacific Island Countries and Territories (PICTs) implemented border entry restrictions and mandatory quarantine in 2020 to prevent imported coronavirus disease (COVID-19). Although some PICTs have experienced large-scale community transmission of COVID-19 (such as Fiji, Papua New Guinea, French Polynesia, and Guam), many PICTs have not (as of January 2022) experienced community transmission, including Vanuatu. Since March 2020, Vanuatu (population 301,695) has restricted entry to citizens and residents and required all incoming travelers to a complete 14-day quarantine period (*1*). As of January 10, 2022, a total of 7 border cases have been reported among travelers in quarantine in Vanuatu, and no community transmission (*2*).

The government of Vanuatu is considering various strategies to remove border restrictions and quarantine, including opening borders, creating travel bubbles with neighboring point-prevalence countries, and restricting entry to vaccinated travelers. We performed mathematical modeling to estimate the expected number of infected arrivals expected for each of these scenarios and through different testing strategies. This modeling complements other modeling that assessed importation risks of COVID-19 with higher point prevalence in the origin countries (*3*) and different outcomes, such as the expected time delay associated with different scenarios (*4*).

We developed an individual stochastic model to estimate the potential number of infectious travelers who would arrive in Vanuatu. We modeled 3 border scenarios and 4 testing strategies (Table). The probability of a traveler being infected on entry into Vanuatu was assumed to be a function of the point prevalence in the country of origin and the distributions of latent, presymptomatic and infectious, and symptomatic (or asymptomatic) infectious periods and test sensitivity. We used point prevalence estimates based on the epidemiologic situation on July 19, 2021, for neighboring countries, including New Caledonia (<0.001%) and New Zealand (0.001%) (*5*).

We assumed that passengers returning with a positive pretravel test result did not travel, those tested on arrival isolated until results were provided, and those tested on day 5 were in the community for 6 days (including time for testing and provision of results). We simulated 10,000 infected travelers stochastically and used 1,000 bootstrap samples to estimate uncertainty intervals. We applied the model to 40,000 passengers (15% of the number of arrivals in 2019) (*6*) (Appendix, https://wwwnc.cdc.gov/EID/article/28/5/21-1757-App1.pdf). We did not include additional variables, such as group size, masking, and hygiene measures.

The number of infectious persons in the community decreased by 98%–99% when travel was restricted entry to persons from low point-prevalence countries, compared with no restrictions on the country of departure for travelers (Figure). The number decreased further, by 61%–63% for each testing strategy, when travel was further restricted to vaccinated travelers only. For all scenarios, the number of infectious persons in the community was inversely proportional to the number of tests conducted. The greatest decrease was observed for testing on arrival (compared with no testing), for which the number of infectious cases in the community decreased by 42%–44%. The proportional decrease was 10%–14% when predeparture plus arrival testing was included. Although adding day 5 testing (in addition to predeparture and on arrival testing) did not result in further

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decrease in the number infectious persons in the community, it did identify 56%–67% of cases after entry, which would enable contact tracing to reduce risk for onward transmission.

Our analysis highlights that the scenario with the greatest importation risk reduction for Vanuatu is travel bubbles with low point-prevalence countries. The risk for case importation through quarantine-free travel with low COVID-19 incidence countries is <3.2 cases/40,000 travelers, an importation risk reduction of ≈100-fold compared with open borders. Several countries in the Pacific region have a low or zero COVID-19 point prevalence (*5*). Furthermore, country-level incidence might decrease as vaccination coverage increases because there is evidence that several COVID-19 vaccines might reduce transmission (*7*). On the basis of our results, many PICTs could be considered for quarantine-free travel with low risk for importation to Vanuatu.

Our results also demonstrate that COVID-19 testing on arrival is useful in all scenarios, but especially for open borders. Testing becomes increasingly useful as the point prevalence of COVID-19 increases in countries of travel origin. Testing 5 days after arrival enables detection of an additional 10%–14% of infections for all scenarios, and these cases can be contact traced and those infected quarantined for part of their infectious period. Since late 2020, Vanuatu has conducted arrival testing for all international arrivals (in addition to routine testing during quarantine). Our results confirm the usefulness of this strategy.

A limitation of our study is that the model does not estimate the number of secondary cases. Assumptions for parameters were based on published evidence for the original variant; these parameters might differ with new and emerging variants. In summary, as Vanuatu and other PICTs move toward removing border restrictions and importation prevention measures, on-arrival testing and restricting entry to travelers from low point-prevalence settings are essential strategies to limit COVID-19 cases.

Table. Characteristics considered in the model for removing border entry and quarantine requirements for coronavirus disease, Vanuatu

Characteristic	Description
Border opening scenarios	
Scenario 1	Open border with no restrictions
Scenario 2	Travel bubble with low point-prevalence neighboring countries
Scenario 3	Travel bubble with low point-prevalence neighboring countries plus vaccination for all incoming travelers
Testing strategies	
Test strategy 1	No testing
Test strategy 2	Testing on arrival only
Test strategy 3	Predeparture plus on arrival
Test strategy 4	Predeparture plus on arrival plus day 5 after arrival

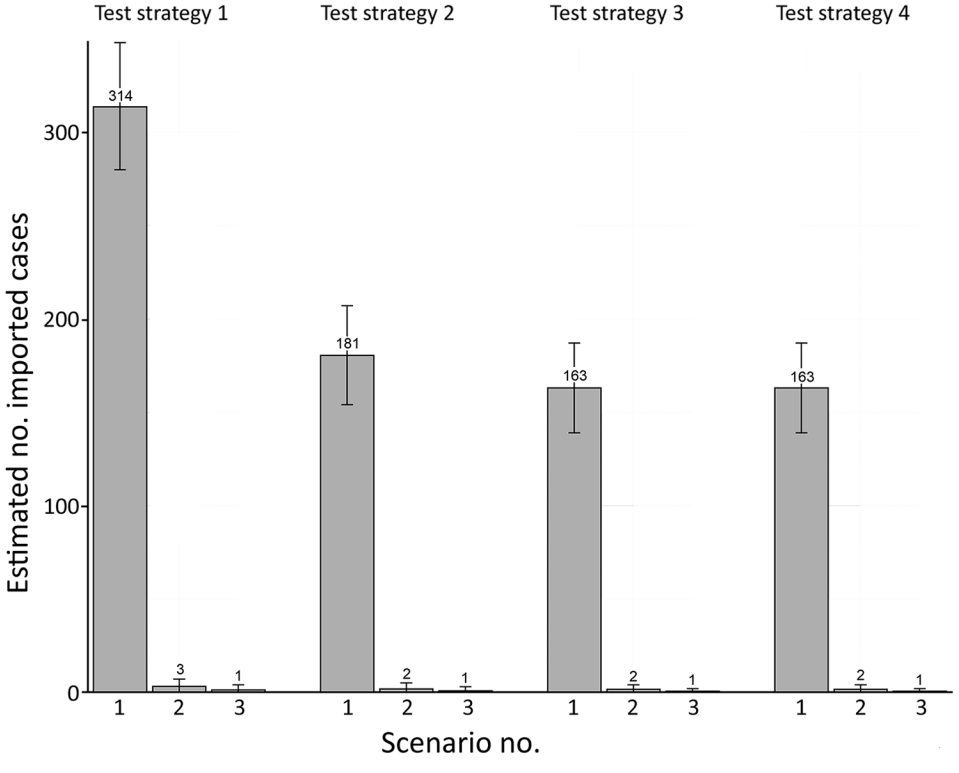

Figure. Number of imported cases of coronavirus disease in the community per 40,000 arrivals, by test strategy and epidemiologic scenario, Vanuatu. Error bars indicate 95% CIs.

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SARS-CoV-2 Seroprevalence after Third Wave of Infections, South Africa

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By November 2021, after the third wave of severe acute respiratory syndrome coronavirus 2 infections in South Africa, seroprevalence was 60% in a rural community and 70% in an urban community. High seroprevalence before the Omicron variant emerged may have contributed to reduced illness severity observed in the fourth wave.

South Africa has experienced 4 waves of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infections, the fourth dominated by the Omicron variant of concern (*1*). Data on the proportion of the population with serologic evidence of previous infection at the time of Omicron emergence are important to contextualize the observed rapid increases and subsequent quick decline in case numbers (*1*), as well as the lower severity compared with previous variants (*2*).

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Appendix

Detailed Methods

An individual stochastic model of infection progression and recovery was used to estimate the risk for imported infection. A simulated sample of incoming travelers was simulated and analyzed in 3 steps:

Step 1: First, 10,000 persons infected with coronavirus disease (COVID-19) were simulated.

Step 2: These persons were sampled by using bootstrap methods to create 3 sets of 1,000 simulated populations of passenger arrivals to Vanuatu for analysis. Each of these populations included 40,000 persons; only a small minority of whom were infected with COVID-19 (0.004%–1% corresponding to ≈1.6–400 infected person/population, depending on the travel restriction scenario).

Step 3: Estimation of the COVID-19 importation risk based if the simulated persons were allowed to enter with no test, compared with scenarios including testing 72 hours before departure, on arrival, and 5 days after arrival.

Step 1: Simulated Population of 10,000 Infected Persons to Sample in Step 2

To simulate the sample of 10,000 infected persons (step 1), each person was assigned a time of infection, incubation period (time from infection to symptom onset), duration of infectiousness before symptom onset, and duration of infectiousness after symptom onset. Hypothetical severe acute respiratory syndrome coronavirus 2 nasopharyngeal swab specimen PCR results were simulated 72 hours before arrival, on arrival, and 5 days after arrival. Test sensitivity was assumed to vary by infectious stage (*1*) and symptom status (*2*): infectious stages

relevant to test sensitivity included the latent stage before infectiousness, presymptomatic, post-symptomatic and asymptomatic infectious stages. The test sensitivities within each stage were calibrated such that the distribution of test results in the infected population followed a similar distribution to the distribution described by Kucirka et al. for analysis of changes in PCR test sensitivity over time (*1*). Distributions for all parameters are summarized in Appendix Table 1.

Step 2: Creation of 3 Sets of 1,000 Simulated Populations of Passenger Arrivals to Vanuatu for Assessment of COVID-19 Importation Risk

Three sets of 1,000 simulated populations of passenger arrivals to Vanuatu were created. Each population of arrivals included 40,000 persons because this was the expected number of international arrivals to Vanuatu in the first year after borders reopened. The number of arrivals in the first year was estimated to be 15% of 2019 levels (n = 256,000) (*9*). Each set of 1,000 simulated populations was designed to capture a particular scenario regarding the probable point prevalence of 7 COVID-1 cases in the population of passenger arrivals (Appendix Table 2). The number of infected persons in each population of passenger arrivals within the set was assigned stochastically by using a Bernouli distribution, with the mean determined by the assumed point prevalence of COVID-19 among arrivals. For each population, infected persons were sampled from the 10,000 infected persons simulated in step 1.

Step 3: Estimation of COVID-19 Importation Risk by Travel Restriction and Testing Policy

The number of imported COVID-19 cases were calculated for each population simulated in Step 2 for each of the following 4 potential PCR testing policies:

1. No testing

2. Testing on arrival. Assume arrivals isolate until the negative result is received.

3. Preflight testing (72 hours before arrival) plus testing on arrival

4. Preflight testing, testing on arrival, and testing 5 days after arrival

Simulated persons were classified as having imported cases if they met the following criteria:

- They were infected in the 2 weeks before arrival in Vanuatu
- At least part of their infectious period was after arrival in Vanuatu

• They were not tested or had a negative test result during preflight and arrival testing

• For those who tested positive 5 days after arrival, part of their infectious period was before the time of the test.

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Appendix Table 1. Distributions of key parameters

Variable	Distribution	Parameters	Reference
Asymptomatic infection	Bernouli	0.35	(*3*)
Timing of infection event before arrival	Uniform	0–14	Assumed
Time from infection event to symptoms	Lognormal	5.5, 2	(*4*)
Duration of presymptomatic infectious period	Lognormal	1,1	(*5,6*)
Duration of symptomatic infectious period	Lognormal	6,2	(*7,8*)
Test sensitivity before infectiousness	Bernouli	1 – test specificity	(*1*)*
Test sensitivity (late latent and early symptomatic period, symptomatic)	Bernouli	0.8	(*1*)*
Test sensitivity (late latent and early symptomatic period, asymptomatic)	Bernouli	0.6	Expert opinion and (*2*)
Test specificity	Bernouli	0.995	Expert opinion

*Infection period specific test sensitivities were calibrated such that the distribution of test results in the infected population followed a similar distribution to the distribution described by Kucirka et al. (*1*) for analysis of changes in PCR test sensitivity over time.

Appendix Table 2. Three scenarios modeled regarding travel restrictions and associated prevalence of coronavirus disease in the population of passenger arrivals

Travel restriction scenario	Assumed point prevalence, %	Source of estimate
No restrictions	1	Prevalence of coronavirus disease in arrivals to Australia, May–June 2020
Travel bubble	0.01	Prevalence of coronavirus disease in neighboring countries of New Caledonia (<0.001%) and New Zealand (0.001%) in July 2021 (*10*)
Travel bubble (vaccinated passengers only)	0.004	60% reduction in prevalence due to vaccination (*11,12*)